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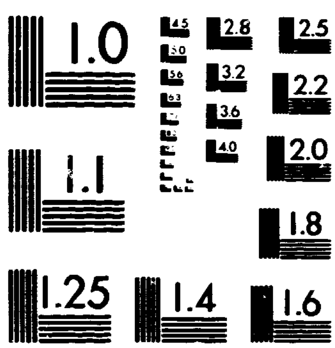

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STRESS CORROSION CRACKING EVALUATION OF MARTENSITIC PRECIPITATION HARDENING STAINLESS STEELS

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16. ABSTRACT

This report gives the results of a comprehensive investigation of the stress corrosion cracking resistance of the martensitic precipitation hardening stainless steels PH13-8Mo, 15-5PH, and 17-4PH. Round tensile and c-ring type specimens taken from several heats of the three alloys were stressed up to 100 percent of their yield strengths and exposed to alternate immersion in salt water, to salt spray, and to a seacoast environment. The results indicate that 15-5PH is highly resistant to stress corrosion cracking in conditions H1000 and H1050 and is moderately resistant in condition H900. The stress corrosion cracking resistance of PH13-8Mo and 17-4PH stainless steels in conditions H1000 and H1050 was sensitive to mill heats and ranged from low to high among the several heats included in the tests. Based on a comparison with data from seacoast environmental tests, it is apparent that alternate immersion in 3.5 percent salt water is not a suitable medium for accelerated stress corrosion testing of these PH stainless steels.

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INTRODUCTION

The precipitation hardening (PH) stainless steels have found considerable application in the aerospace industry because they are high strength, corrosion resistant materials that can be hardened after machining by a low temperature, distortion-free heat treatment. The PH stainless steels are basically of two types, martensitic and semi-austenitic. Both types possess excellent corrosion resistance, but the martensitic alloys exhibit the higher resistance to stress corrosion cracking (SCC). Only the martensitic PH stainless steels are covered in this investigation.

Like the hardenable straight chromium stainless steels, the PH stainless steels may under certain conditions of tensile stress and corrosive environment suffer SCC. The martensitic PH stainless steels (PH13-8Mo, 15-5PH, and 17-4PH) were previously reported to exhibit very high resistance to SCC [1,2,3] especially in the upper range (810-895 K) of the age hardening temperature. These results were obtained with limited SCC tests in alternate immersion (A.I.) in salt water and specimens from wire and sheet material exposed to a coastal marine environment. Some recent results, using short transverse specimens from PH13-8Mo bar and 17-4PH plate, indicated that these materials were susceptible to SCC in a seacoast environment even though no failures had been encountered in prior SCC tests of these materials by alternate immersion in salt water. These results were in agreement with those reported by Douglas Aircraft Company, who found that salt spray was the most severe test medium followed by marine atmosphere and then alternate immersion for SCC evaluation of AM-350 stainless steel [4]. Because of this discrepancy in SCC test results, a more comprehensive test program was undertaken to evaluate the SCC resistance of the martensitic PH stainless steels PH13-8Mo, 15-5PH, and 17-4PH.

EXPERIMENTAL PROCEDURE

The types of PH stainless steels evaluated in this investigation were PH13-8Mo, 15-5PH, and 17-4PH in the form of plate, bar, and forging. Two types of specimens were required because of differences in size of the test material. Round tensile specimens stressed uniaxially were used in all cases where the size of the product permitted. C-rings were used where the size of the material was such that appropriate tensile specimens could not be obtained.

The specimens were strained or deflected the calculated amount to obtain the desired stress levels. The stressing fixtures and specimen ends were dipped in a strippable coating (Maskcoat No. 2, Western Coating Company) to protect the fixtures and to prevent possible galvanic effect between the specimens and the fixtures. Specimens exposed to the seacoast atmosphere were not coated with the strippable maskant because the maskant deteriorates rapidly in sunlight. Instead, the ends of the specimens and the areas of the stressing frames in contact with the specimens were coated with a neoprene cement (MSFC X94). After wiping the exposed areas with alcohol, the specimens were placed in one of three chosen test media: alternate immersion in 3.5 percent salt water, 5 percent salt spray, or the seacoast environment at Kennedy Space Center. A detailed description of the specimens, formulas for calculating strain and deflection, and methods of loading and testing the specimens are given in Reference 5. Where feasible, mechanical properties of each test material were measured in all grain directions of testing. The chosen stress ranged from 25 to 100 percent of the directional yield strength. In those cases where the directional yield strength was not measured because of insufficient cross section, the calculated stress was based on the yield strength of a measured direction, longitudinal or long transverse.

RESULTS AND DISCUSSION

The compositions of the test materials are given in Table 1 and are all within specifications. Table 2 lists the mechanical properties of all heats and tempers of the three PH stainless steels. The stress corrosion cracking results obtained in salt spray and seacoast atmosphere are shown in Table 3 and the SCC results of selected materials tested in all three environments (A.I. in salt water, salt spray, and seacoast) for comparison are given in Table 4.

The martensitic 15-5PH stainless steel was found to possess very high resistance to SCC in the H1000 and H1050 conditions in that no failures were encountered even when the material was stressed to 100 percent of the 0.2 percent offset yield strength. Failures occurred with this alloy in the fully hardened H900 condition but only at a very high stress, 100 percent of the yield strength.

The SCC resistance of PH13-8Mo and 17-4PH varied significantly from heat to heat. The 7.6 by 15 cm diameter bars and the 2.5 by 15 cm bar of PH13-8Mo exhibited very high resistance to SCC, whereas the 18 cm diameter bar and the 7.6 by 15 cm bar showed an intermediate resistance. Both the 18 by 38 by 61 cm forging and the 5.7 by 15 cm bar of PH13-8Mo exhibited relatively low resistance to SCC, and the results of the intermediate and low resistant materials were erratic. For example, failures occurred at 50 percent stress level and not at 75 and 100 percent, or failures occurred at 75 and not at 100 percent stress. The 3.8 cm diameter bar and the 1.9 by 3.8 cm bar of 17-4PH exhibited high resistance to SCC, and the only failures encountered in the 7.6 by 15 cm bar occurred outside the reduced section at the edge or under the strippable maskant. It may also be noted in Table 3 that none of the specimens taken from the 7.6 by 15 cm bar failed at the seacoast. The remaining 17-4PH material (3.8 and 7.6 cm diameter bars and 5.4 cm plate) was susceptible to SCC.

The relatively low SCC resistance of PH13-8Mo and 17-4PH was surprising, especially the poor performance of PH13-8Mo. Both PH13-8Mo and 15-5PH stainless steels are produced by consumable electrode vacuum arc remelting (VAC CE), and, in addition, PH13-8Mo is vacuum induction melted (VAC IND). According to the producer, VAC CE controls chemical composition within narrow limits, reduces and disperses inclusions, minimizes alloy segregation during solidification, and eliminates delta ferrite in the material. This should not only improve mechanical properties but should improve the SCC resistance as compared to air melting, the method by which the 17-4PH materials was produced.

Metallographic examinations of all the test materials revealed the presence of a segregated phase compound of delta ferrite stringers, and grain boundary carbides in the microstructures of the PH13-8Mo and 17-4PH stainless steels. As illustrated in Figures 1 through 9, the microstructure varied significantly among the various heats of both alloys. For example, no stringers were detected in the 7.6 by 15 cm bar or 13 cm diameter bar of PH13-8Mo (Fig. 1), but numerous stringers and carbides were present in the 18 by 38 by 61 cm forging and the 5.4 by 15 cm bar as shown in Figure 4 and the top view of Figure 5. The variation in the frequency and size of the stringers present in the microstructures of several heats of 17-4PH stainless steel is illustrated in Figure 7.

An attempt to correlate the SCC resistance with the microstructures of the various heats of the three PH stainless steels was only partially successful. In general, the heats (2W0328, 1X1285, and 690254 — Figures 4, 5, 7, 9) that contained the most stringers and carbide participate were the most susceptible to SCC. The major exception was the 3.8 cm square bar (Fig. 7) which contained numerous small stringers but was resistant to SCC. The microstructures of the 7.6 by 6 cm and 13 cm diameter PH13-8Mo bars appear to be practically free of stringers and precipitates (Fig. 1), but failures were encountered in the former and not the latter bar (Table 3). The 15-5PH material which was highly resistant to SCC was practically free of stringers and precipitates (Fig. 6). The brittle nature of stringer failure is shown in Figure 5 which is indicative of SCC as illustrated in Figure 10.

The SCC results of selected PH stainless steels tested in three environments (A.I. in salt water, salt spray, and seacoast) clearly indicate that A.I. in salt water is not sufficiently aggressive for use as an accelerated SCC test medium for these steels (Table 4). As can be observed in Tables 3 and 4, the results obtained in salt spray agree favorably with those obtained at the seacoast and thus salt spray appears to be a suitable laboratory test medium for SCC evaluation of martensitic PH stainless steels.

CONCLUSIONS

The results obtained in this investigation revealed that:

1) Alloy 15-5PH stainless steel is highly resistant to SCC in conditions H1000 and H1050 and is moderately resistant in its highest strength condition (H900).

2) The SCC resistance of PH13-8Mo and 17-4PH stainless steels varied from low to high among various heats even in conditions H1000 and H1050.

3) Except for the 5.4 cm plate of 17-4PH, both PH13-8Mo and 17-4PH stainless steels exhibited higher resistance to SCC in condition H1050 than in condition H1000, especially in the seacoast test.

4) Alternate immersion in salt water is not a suitable test medium for evaluating the SCC resistance of these martensitic PH stainless steels.

5) Salt spray appears to be an acceptable medium for use in SCC testing of PH stainless steels, and the results agree favorably with those obtained in seacoast exposure.

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TABLE 1. CHEMICAL ANALYSIS OF PH STAINLESS STEELS

Heat No.	Source	Form	C	Mn	P	S	Si	Cr	Ni	Mo	Al	N	Cu	Cb+Ta
							PH13-8Mo Stainless Steel							
3W1283	Armco	7.6 x 15 cm Bar	.035	.01	.002	.004	.01	12.58	8.11	2.17	1.11	.0025		
1W1301	Armco	7.6 cm Dia. Bar	.030	.02	.002	.006	.02	12.62	8.22	2.15	1.01	.0025		
4W1301	Armco	2.5 x 15 cm Bar	.035	.01	.002	.004	.02	12.53	8.30	2.18	1.00	.0043		
1X1285	Armco	18 x 38 x 61 cm Forg.	.033	.03	.002	.003	.04	12.55	8.21	2.15	.97	.0021		
2W022[illegible]	Armco	5.7 x 15 cm Bar	.045	.01	.002	.003	.01	12.76	8.20	2.13	1.20	.004		
1V0155	Armco	13 cm Dia. Bar	.038	.01	.002	.002	.01	12.66	8.29	2.13	1.10	.005		
Unknown (1) (2)	-	18 cm Dia. Bar		.05			.05	13.2	6.8	1.9	1.27			
							15-5 PH Stainless Steel							
20182-5	Al Tech	7.6 x 15 cm Bar	.047	.51	.024	.007	.53	14.87	4.75	.28			3.35	.40
20260-6	Al Tech	7.6 cm Dia. Bar	.045	.41	.026	.002	.31	14.55	4.58	.50			3.25	.36
1X0227	Armco	5.7 x 15 cm Bar	.037	.28	.019	.009	.35	15.13	4.50				3.38	.28
							17-4 PH Stainless Steel							
A16495	Crucible	7.6 x 15 cm Bar	.043	.69	.040	.015	.49	16.07	4.16				3.23	.31
A16600	Crucible	7.6 cm Dia. Bar	.060	.38	.031	.016	.44	15.89	4.36				3.28	.33
690254	-	5.4 cm Plate	.040	.31	.019	.014	.48	16.22	4.32				3.39	.28
Unknown (1)	-	3.8 cm Dia. Bar		.27			.48	17.0	4.5				4.2	.24
Unknown (1)	-	3.8 x 3.8 cm Bar		.33			.60	16.5	3.6				4.1	.37
Unknown (1)	-	1.9 x 3.8 cm Bar		.58			.68	16.5	3.8				3.8	.39

NOTE: (1) MSFC analysis - remainder are producers certified analysis.
(2) Results may be inaccurate because the area of the sample available for spectrographic analysis was limited.

TABLE 2. MECHANICAL PROPERTIES OF PH STAINLESS STEELS

Heat No.	Form	Temper	Grain Direction	T. S. MPa	T. S. (ksi)	Y. S. MPa	Y. S. (ksi)	% El
			PH13-8Mo Stainless Steel					
3W1283	7.6 x 15 cm Bar	H-1000	ST	1441	209	1407	204	8
		H-1050	ST	1289	187	1262	183	9
		H-1000	LT	1434	208	1393	202	8
		H-1050	LT	1269	184	1248	181	10
1W1301	7.6 cm Dia. Bar	H-1000	Tr	1407	204	1386	201	8
		H-1050	Tr	1248	181	1248	181	9
4W1301	2.5 x 15 cm Bar	H-1000	LT	1393	202	1365	198	8
		H-1050	LT	1282	186	1276	185	9
1X1285	18 x 38 x 61 cm Forg.	H-1000	ST	1407	204	1393	202	7
		H-1050	ST	1207	175	1151	167	12
		H-1000	LT	1407	204	1393	202	7
		H-1050	LT	1213	176	1165	169	10
2W0328	5.7 x 15 cm Bar	H-950	ST	1503	218	1365	198	12
		H-950	LT	1510	219	1365	198	16
		H-950	LO	1531	222	1420	206	16
		H-1000	ST	1407	204	1331	193	18
		H-1000	LT	1427	207	1338	194	15
		H-1000	LO	1413	205	1338	194	17
		H-1050	ST	1296	188	1227	178	7
		H-1050	LT	1248	181	1158	168	9
		H-1050	LO	1262	183	1186	172	8
1V0155	13 cm Dia. Bar	H-950	Tr	1551	225	1469	213	16
		H-1000	Tr	1455	211	1413	205	16
Unknown	18 cm Dia. Bar	H-1000	Tr	1400	203	1365	198	7
		H-1050	Tr	1324	192	1269	184	6
			15-5PH Stainless Steel					
20182-5	7.6 x 15 cm Bar	H-1000	ST	1138	165	1130	160	9
		H-1050	ST	1103	160	1089	158	10
		H-1000	LT	1131	164	1089	158	9
		H-1050	LT	1103	160	1076	156	9

TABLE 2. (Concluded)

Heat No.	Form	Temper	Grain Direction	T. S. MPa	T. S. (ksi)	Y.S. MPa	Y.S. (ksi)	% El
20260-6	7.6 cm Dia. Bar	H-1000	Tr	1165	169	1131	164	14
		H-1050	Tr	1117	162	1089	158	16
1X0227	5.7 x 15 cm Bar	H-900	ST	1317	191	1172	170	20
		H-1000	ST	1145	166	1062	154	19
			17-4 PH Stainless Steel					
A16495	7.6 x 15 cm Bar	H-1000	ST	1103	160	1062	154	7
		H-1050	ST	1076	156	1054	153	7
		H-1000	LT	1103	160	1076	156	9
		H-1050	LT	1069	155	1041	151	9
		H-1000	LO	1110	161	1082	157	10
A16600	7.6 cm Dia. Bar	H-1000	Tr	1103	160	1041	151	8
		H-1050	Tr	1069	155	993	144	9
690254	5.4 cm Plate	H-900	ST	1269	184	1158	168	3
		H-1000	ST	1124	163	1089	158	5
		H-1050	ST	1082	157	1054	153	4
		H-900	LT	1317	191	1200	174	18
		H-1000	LT	1248	181	1179	171	16
		H-900	LO	1351	196	1241	180	16
		H-1000	LO	1151	167	1110	161	18
Unknown	3.8 cm Dia. Bar	H-900	LO	1413	205	1408	204	16
		H-1000	LO	1145	166	1131	164	19
Unknown	3.8 cm Sq. Bar	H-900	LO	1338	194	1200	174	19
		H-1000	LO	1138	165	1096	159	20
Unknown	1.9 x 3.8 cm Bar	H-900	LO	1324	192	1193	173	23
		H-1000	LO	1131	164	1089	158	23

TABLE 3. STRESS CORROSION CRACKING RESULTS OF PH STAINLESS STEELS[1]

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	Salt Spray F/N[2]	Days	Seacoast F/N[2]	Days
		PH13-8Mo 7.6 x 15 cm Bar (3W1283)						
ST	H1000	704	102	50	1/3	<180[4]	0/5	
		1056	153	75	0/3		2/5	82, 153
		1407	204	100	0/3		0/5	
ST	H1050	631	92	50	0/3		0/5	
		947	137	75	0/3		0/5	
		1262	183	100	0/3		1/5	55
LT	H1000	697	101	50	0/3		0/5	
		1045	152	75	1/3	<180[4]	0/5	
		1393	202	100	1/3	74[4]	0/5	
LT	H1050	624	91	50	0/3		0/5	
		936	136	75	0/3		0/5	
		1248	181	100	0/3		0/4	
		PH13-8Mo 7.6 cm Diameter Bar (1W1301)						
Tr	H1000	693	101	50	0/3		0/5	
		1040	151	75	0/3		0/5	
		1386	201	100	0/3		0/5	
Tr	H1050	624	91	50	0/3		0/5	
		936	136	75	0/3		0/5	
		1248	181	100	0/3		0/5	
		PH13-8Mo 2.5 x 15 cm Bar (4W1301)						
ST (C-Ring)	H1000	683	99	50	0/3		0/5	
		1024	149	75	0/3		0/5	
		1365	198	100	0/3		0/5	
LT	H1000	683	99	50	0/3		0/5	
		1024	149	75	0/3		0/5	
		1365	198	100	0/3		0/5	
LT	H1050	648	93	50	0/3		0/5	
		957	139	75	0/3		0/5	
		1276	185	100	0/3		0/5	

TABLE 3. (Continued)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	Salt Spray F/N(2)	Days	Seacoast F/N(2)	Days
			PH13-8Mo 18 x 38 x 61 cm Forging (1X1285)					
ST	H1000	348	51	25			0/4	
		697	101	50	0/5		4/4	22,34,37,91
		1045	152	75	2/5	35,37	4/4	16,55,62,336
		1393	202	100	2/5	35,71		
ST	H1050	288	42	25			0/4	
		576	84	50	2/5	17,86	0/4	
		863	125	75	0/5		0/4	
		1151	167	100	1/5	9		
LT	H1000	697	101	50	1/3	32	3/3	13,16,82
		1045	152	75	0/3			
		1393	202	100	1/3	42		
LT	H1050	291	42	25			0/3	
		583	85	50	1/3	28	0/3	
		874	127	75	1/3	15	0/3	
		1165	169	100	1/3	28		
			PH13-8Mo 5.7 x 15 cm Bar (2W0328)					
ST	H950	1024	149	75	2/3	7, 27	1/5	2
		1365	198	100	5/6	3,10,10,13,17	3/5	1,5,69
LT	H950	1024	149	75	1/3	15		
		1365	198	100	0/3			
LO	H950	1065	155	75	0/3			
		1420	206	100	0/3			
ST	H1000	333	48	25	0/3		0/3	
		666	97	50	1/3	8	0/3	
		998	145	75	4/9	2,7,10 <180	2/5	2,2
		1331	193	100	4/7	10,10,13,27	0/5	
ST	H1000	333	48	25	0/3		0/5	
(0.6 cm		666	97	50	3/3	7,43,139	3/5	16,51(4) 106
Dia.)		998	145	75	2/3	7,7		
ST	H1000	666	193	50	0/3			
(C-Ring)		998	145	75	0/3			
LT	H1000	335	49	25			0/3	
		669	97	50	1/6	30	0/3	
		1004	146	75	2/6	13,21		
		1338	194	100	0/3			

TABLE 3. (Continued)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	Salt Spray F/N(2)	Days	Seacoast F/N(2)	Days
LO	H1000	335	49	25			0/3	
		669	97	50	0/3		0/3	
		1004	146	75	0/3			
		1338	194	100	2/3	7,7		
ST	H1050	307	45	25	0/3		0/3	
		614	89	50	1/3	44	0/3	
		921	134	75	2/3	7,43		
ST	H1050	614	89	50	0/3			
(C-Ring)		921	134	75	0/3			
LT	H1050	290	42	25			0/3	
		579	84	50	0/3		0/3	
		869	126	75	1/3	45		
LO	H1050	297	44	25			0/3	
		593	87	50	1/3	28	0/3	
		890	131	75	1/3	70		
PH13-8Mo 13 cm Diameter Bar (1V0155)								
Tr	H950	1102	160	75	0/3			
		1469	213	100	0/3			
Tr	H1000	1060	154	75	0/3			
		1413	205	100	1/3	13		
PH13-8Mo 18 cm Diameter Bar								
Tr	H1000	342	50	25			0/4	
		683	99	50	0/4		0/4	
		1025	149	75	1/4	180		
Tr	H1050	318	46	25			0/4	
		635	92	50	1/4	45	0/4	
		1053	138	75	1/4	24		
15-5PH 7.6 x 15 cm Bar (20182-5)								
ST	H1000	565	80	50	0/4		0/5	
		848	120	75	0/3		0/5	
		1130	160	100	0/3		0/5	

TABLE 3. (Continued)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	Salt Spray F/N(2)	Days	Seacoast F/N(2)	Days
ST	H1050	545	79	50	0/3		0/5	
		817	119	75	0/3		0/5	
		1089	158	100	0/3		0/5	
LT	H1000	545	79	50	0/3		0/5	
		817	119	75	0/3		0/5	
		1089	158	100	0/3		0/5	
LT	H1050	538	78	50	0/3		0/5	
		807	117	75	0/3		0/5	
		1076	156	100	0/3		0/5	
		15-5PH 7.6 cm Diameter Bar (20260-6)						
Tr	H1000	566	82	50	0/3		0/5	
		848	123	75	0/3		0/4	
		1131	164	100	0/3		0/4	
Tr	H1050	545	79	50	0/3		0/5	
		817	119	75	0/3		0/4	
		1089	158	100	0/3		0/4	
		15-5PH 5.7 x 15 cm Bar (1X0227)						
ST	H900	879	128	75			0/5	
		1172	170	100	1/2	<180	2/5	366, 384
ST	H1000	797	116	75			0/5	
		1062	154	100	0/4		0/5	
		17-4PH 7.6 x 15 cm Bar (A16495)						
ST	H1000	531	77	50	0/3		0/5	
		797	116	75	0/3		0/5	
		1062	154	100	1/3	23(4)	0/5	
ST	H1050	527	77	50	0/3		0/5	
		791	115	75	0/3		0/5	
		1054	153	100	1/3	65(4)	0/5	
LT	H1000	538	78	50	0/3		0/5	
		807	117	75	1/3	158(4)	0/5	
		1076	156	100	2/3	23(4), 26(4)	0/5	
LT	H1050	521	76	50	0/3		0/5	
		781	113	75	0/3		0/5	
		1041	151	100	2/3	29(4), 58(4)	0/5	

TABLE 3. (Continued)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	Salt Spray F/N(2)	Days	Seacoast F/N(2)	Days
LO	H1000	541	79	50	0/3			
		812	118	75	0/3			
		1082	157	100	0/3			
17-4PH 7.6 cm Diameter Bar (A16600)								
Tr	H1000	521	76	50	0/3		0/5	
		781	113	75	1/3	24	1/5	76
		1041	151	100	2/3	16,45	0/5	
Tr	H1050	497	72	50	0/3		0/5	
		745	108	75	0/3		0/5	
		993	144	100	2/3	31,36	1/5	13
17-4PH 5.4 cm Plate (690254)								
ST	H900	869	126	75	2/3	6,14	0/5	
		1158	168	100	3/3	2,6,35	0/5	
ST	H1000	272	40	25	0/3		0/5	
		545	79	50	0/3		5/10	5,7,12,68,336,
		817	119	75	3/6	7,12,16	8/10	5,6,7,20,40,13 57,76
		1089	158	100	3/3	2,6,15		
ST	H1050	264	39	25	0/3		1/5	82
		527	77	50	0/3		1/5	47
		791	116	75	3/3	7,7,8	3/5	43,47,55
LT	H900	900	131	75	0/3			
		1200	174	100	1/3	139		
LT	H1000	884	128	75	0/3			
		1179	171	100	0/3			
LO	H900	931	135	75	0/3			
		1241	180	100	0/3			
LO	H1000	833	121	75	0/3			
		1110	161	100	0/3			
ST	H900	869	126	75	0/3(3)			
(C-Ring)		1158	168	100	o/2(3)			
ST	H1000	817	119	75	0/3(3)			
(C-Ring)		1089	158	100	0/3(3)			

TABLE 3. (Continued)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	Salt Spray F/N[2]	Days	Seacoast F/N[2]	Days
		17-4PH 3.8 cm Diameter Bar[3]						
Tr (C-Ring)	H900	1055	153	75	1/2	62		
		1407	204	100	2/3	62,62		
Tr (C-Ring)	H1000	848	123	75	0/3			
		1131	164	100	0/3			
LO	H900	1055	153	75	0/3			
		1407	204	100	0/3			
LO	H1000	848	123	75	0/3			
		1131	164	100	0/3			
		17-4PH 3.8 cm Square Bar[3]						
Tr (C-Ring)	H900	900	131	75	0/3			
		1200	174	100	0/3			
Tr (C-Ring)	H1000	822	119	75	0/3			
		1096	159	100	0/3			
LO	H900	900	131	75	0/3			
		1200	174	100	0/3			
LO	H1000	822	119	75	0/3			
		1096	159	100	0/3			
		17-4PH 1.9 x 3.8 cm Bar[3]						
ST (C-Ring)	H900	895	129	75	0/2			
		1193	173	100	0/3			
ST (C-Ring)	H1000	817	119	75	0/2			
		1089	158	100	0/2			
LT (C-Ring)	H900	895	129	75	0/2			
		1193	173	100	0/3			
LT (C-Ring)	H1000	817	119	75	0/2			
		1089	158	100	0/2			
LO	H900	895	129	75	0/2			
		1193	173	100	0/3			
LO	H1000	817	119	75	0/2			
		1089	158	100	0/3			

TABLE 3. (Concluded)

NOTE: (1) Test Data

a. Specimen: 0.3 cm diameter tensile unless noted otherwise.

b. Exposure time: Until failure or 6 months for salt spray and 14 months for seacoast.

(2) F/N: Ratio of failures to total number of specimens exposed.

(3) These C-rings and tensiles were exposed to A.I. for 6 months, and then they were unloaded, cleaned, vapor blasted, restressed, and exposed for 3 months to salt spray.

(4) Specimens broke under the coating or at coating - specimen interface; all others broke in reduced section.

TABLE 4. COMPARISON OF TEST RESULTS IN THREE TEST MEDIA[1]

Stress Direction	Temper	Applied Stress MPa	Applied Stress ksi	Applied Stress % Y.S.	A.I. F/N(2)	A.I. Days	Salt Spray F/N(2)	Salt Spray Days	Seacoast F/N(2)	Seacoast Days
		PH13-8Mo 5.7 x 15 cm Bar (2W0328)								
ST	H950	1024	149	75	0/3		2/3	7,27	1/5	2
		1365	198	100	0/3		5/6	3-17	3/5	1,5,69
ST	H1000	998	145	75	0/3		4/9	2,7,10,<180	2/5	2,2
		1331	193	100	0/3		4/7	10,10,13,27	0/5	
LT	H950	1024	149	75	0/3		1/3	15		
		1365	198	100	0/3		0/3			
LT	H1000	1004	146	75	0/3		2/6	13,21		
		1338	194	100	0/3		0/3			
LO	H950	1065	155	75	0/3		0/3			
		1420	206	100	0/3		0/3			
LO	H1000	1004	146	75	0/3		0/3			
		1338	194	100	0/3		2/3	7,7		
		PH13-8Mo 13 cm Diameter Bar (1V0155)								
Tr	H950	1102	160	75	0/3		0/3			
		1469	213	100	0/3		0/3			
LO	H1000	1060	154	75	0/3		0/3			
		1413	205	100	0/3		1/3	13		
		15-5PH 5.7 x 15 cm Bar (1X0227)								
ST	H900	1172	170	100	2/2	156, 158	1/2	<180	2/5	366,384
ST	H1000	1062	154	100	0/4		0/4		0/5	
		17-4PH 5.4 cm Plate (690254)								
ST	H900	869	126	75	0/3		2/3	6,14	0/5	
		1158	168	100	0/3		3/3	2,6,35	0/5	
[illegible]	H1000	817	119	75	0/3		1/3	12	8/10	5,6,7,20, 40,13,57, 76
		1089	158	100	0/3		3/3	2,6,15		

TABLE 4. (Continued)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	A.I. F/N[2]	Days	Salt Spray F/N[2]	Days	Seacoast F/N[2]	Days
		17-4PH 5.4 cm Plate (690254)								
LT	H900	900	131	75	0/3		0/3			
		1200	174	100	0/3		1/3	139		
LT	H1000	884	128	75	0/3		0/3			
		1179	171	100	0/3		0/3			
LO	H900	931	135	75	0/3		0/3			
		1241	180	100	0/3		1/3	13		
LO	H1000	833	121	75	0/3		0/3			
		1110	161	100	0/3		0/3			
ST	H900	900	131	75	0/3		0/3(3)			
(C-Ring)		1200	174	100	1/3	1	0/2(3)			
ST	H1000	884	128	75	0/3		0/3(3)			
(C-Ring)		1179	171	100	0/3		0/3(3)			
		17-4PH 3.8 cm Diameter Bar(3)								
Tr	H900	1055	153	75	0/3		1/2	62		
(C-Ring)		1407	204	100	0/3		2/3	62,62		
Tr	H1000	848	123	75	0/3		0/3			
(C-Ring)		1113	164	100	0/3		0/3			
LO	H900	1055	153	75	0/3		0/3			
		1407	204	100	0/3		0/3			
LO	H1000	848	123	75	0/3		0/3			
		1113	164	100	0/3		0/3			
		17-4PH 3.8 cm Square Bar(3)								
Tr	H900	900	129	75	0/2		0/2			
(C-Ring)		1200	173	100	0/3		0/3			
Tr	H1000	822	119	75	0/3		0/3			
(C-Ring)		1096	158	100	0/3		0/3			
LO	H900	900	129	75	0/3		0/3			
		1200	173	100	0/3		0/3			
LO	H1000	822	119	75	0/3		0/3			
		1096	158	100	0/3		0/3			

TABLE 4. (Concluded)

Stress Direction	Temper	Applied Stress MPa	ksi	% Y.S.	A.I. F/N[2]	Days	Salt Spray F/N[2]	Days	Seacoast F/N[2]	Days
		17-4PH 1.9 x 3.8 cm Bar[3]								
ST (C-Ring)	H900	895	129	75	0/3		0/3			
		1193	173	100	0/3		0/3			
ST (C-Ring)	H1000	817	119	75	0/3		0/3			
		1089	158	100	0/3		0/3			

NOTE: (1) Test Data:

a. Specimens: 0.3 cm diameter tensile unless noted.

b. Total Exposure Time: Six months for A.I. and salt spray and 14 months for seacoast.

(2) F/N: Ratio of failures to total number of specimens exposed.

(3) These C-rings and tensile specimens were exposed to A.I. for 6 months, then they were unloaded, cleaned, vapor blasted, restressed, and exposed for 3 months to salt spray.

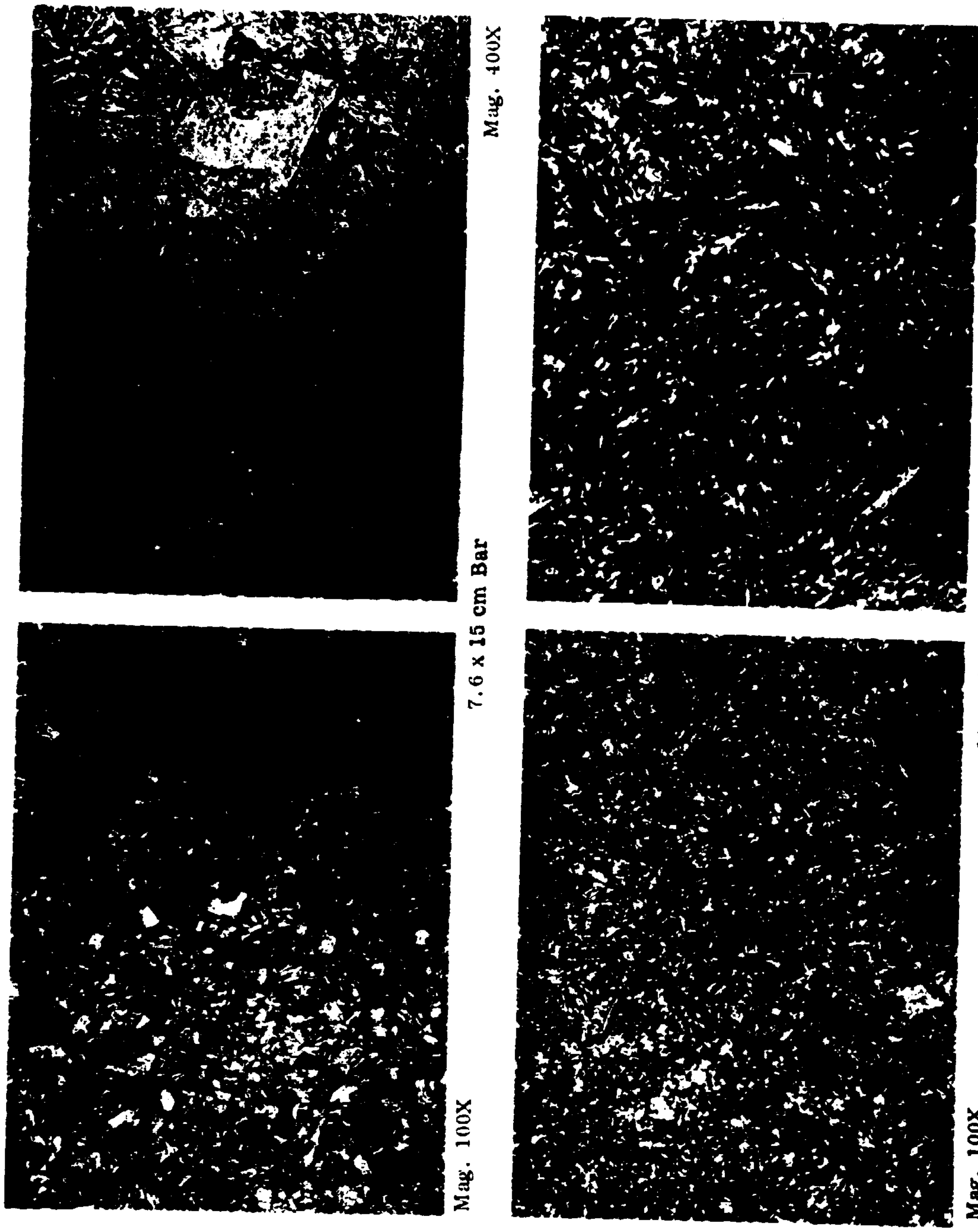


Figure 1. Photomicrographs of PH13-8Mo bars showing representative structure free of stringers and carbide precipitate.

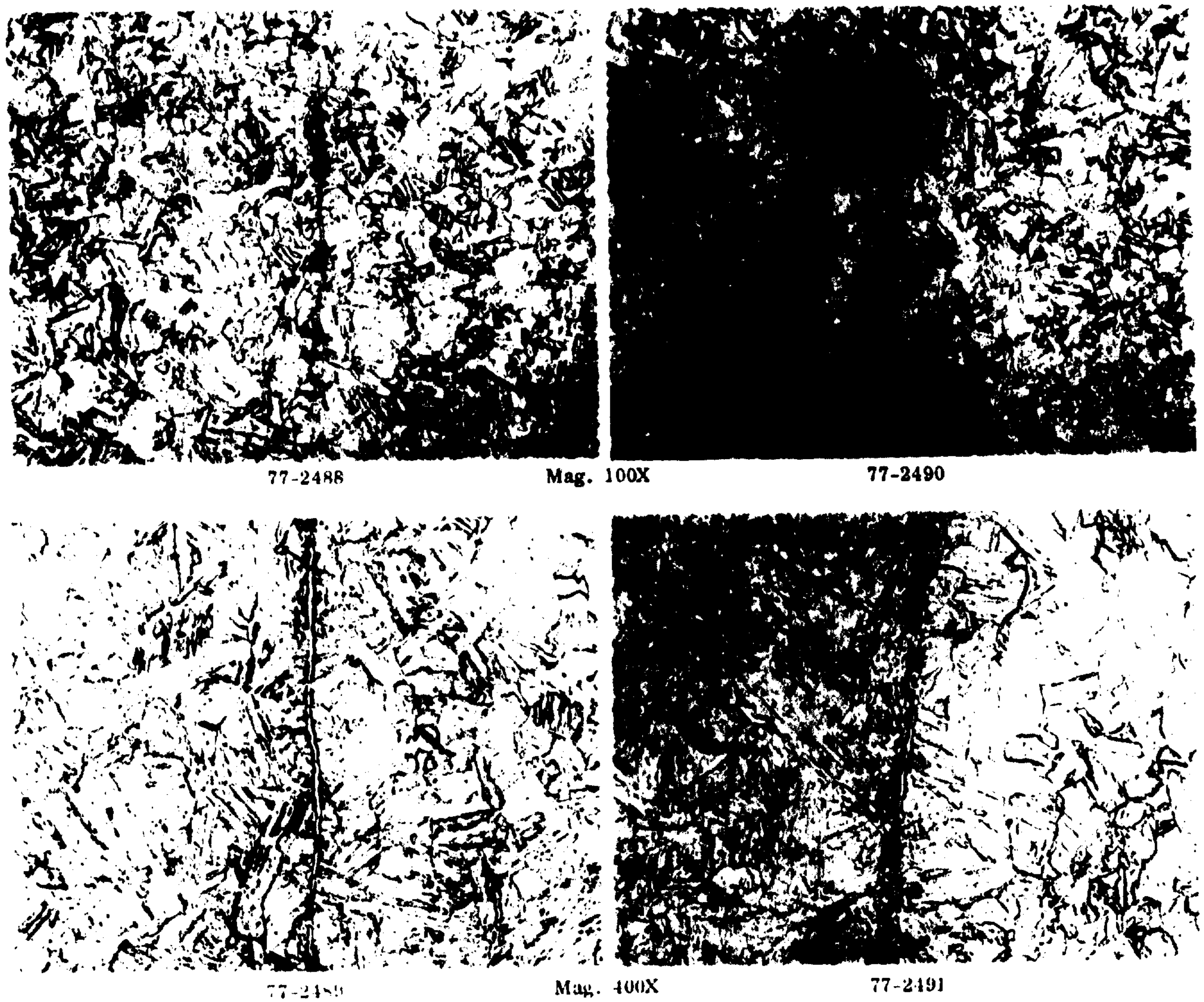
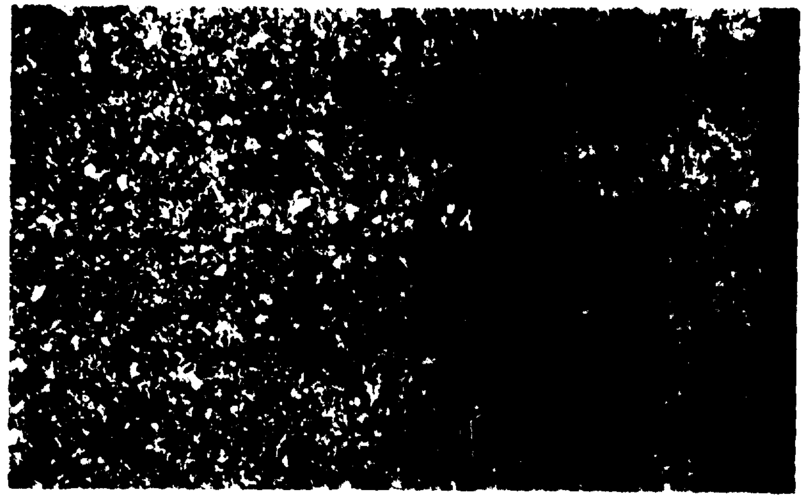
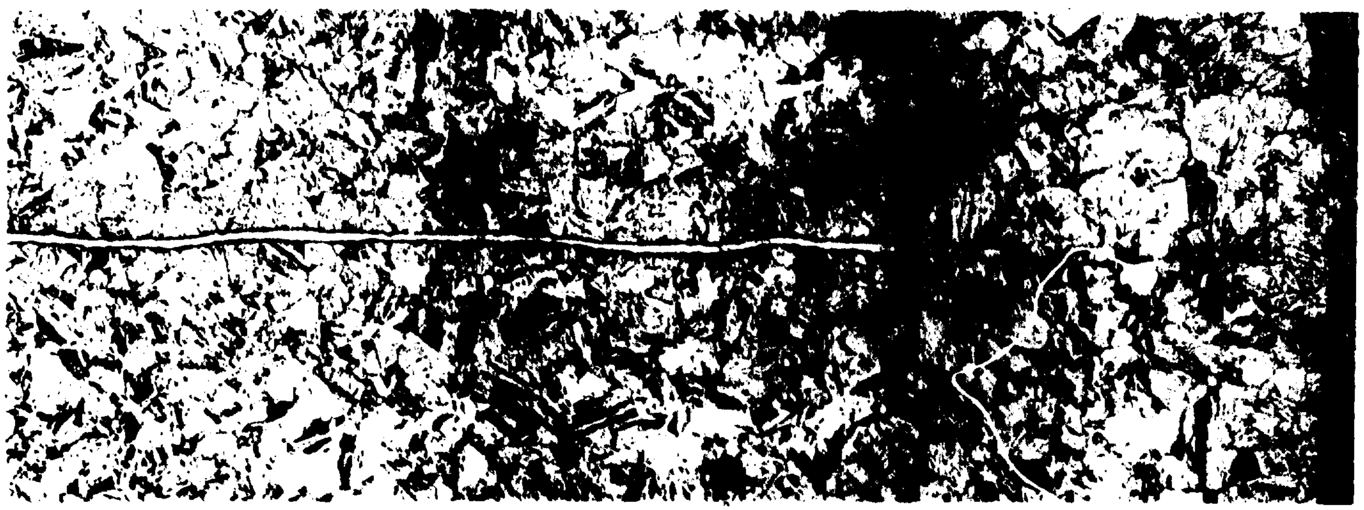


Figure 2. Microstructure of 7.6 cm diameter PH13-8Mo bar showing two stringers.

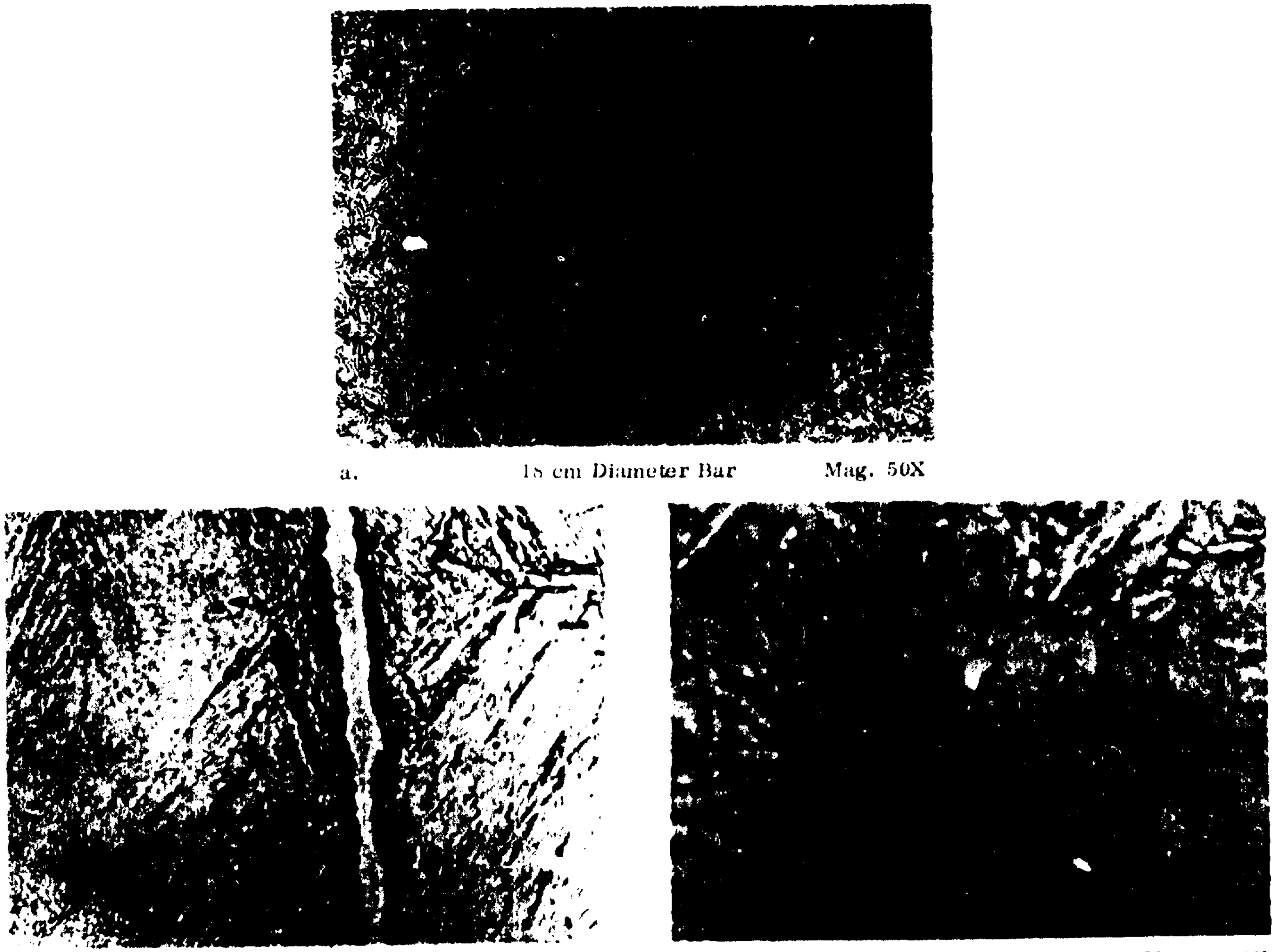


77-2179 Mag. 100X 77-2180



77-2183 Mag. 400X 77-2181

Figure 3. Microstructure of 2.5 by 15 cm PH13-8Mo bar showing a single stringer.

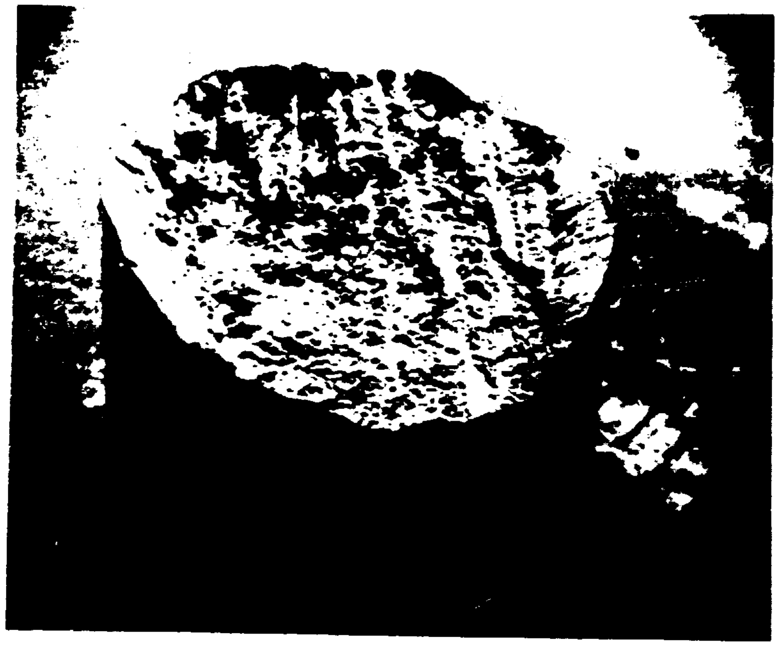


a. 18 cm Diameter Bar Mag. 50X

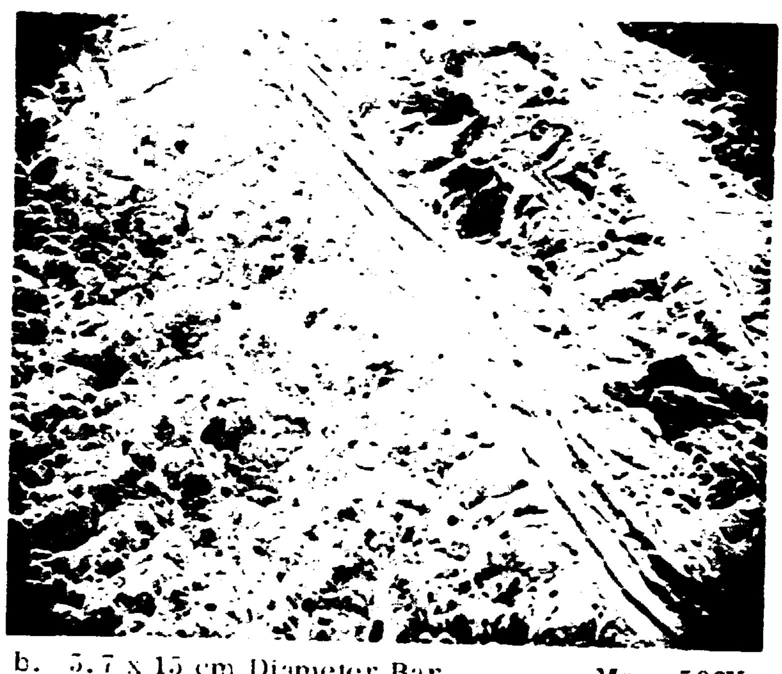
b. 18 x 38 x 61 cm Forging Mag. 800X

c. 5.7 x 15 cm Bar Mag. 1600X

Figure 4. Photomicrographs of PH13-8Mo bars showing (a) areas of non-uniform martensitic structure, (b,c) stringers and chromium carbides.

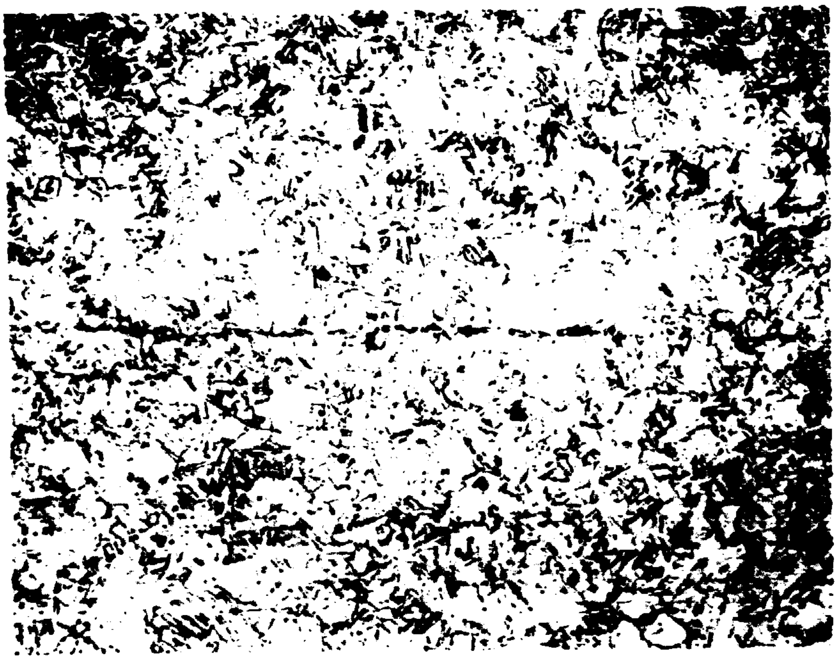


a. 5.7 x 15 cm Diameter Bar Mag. 20X

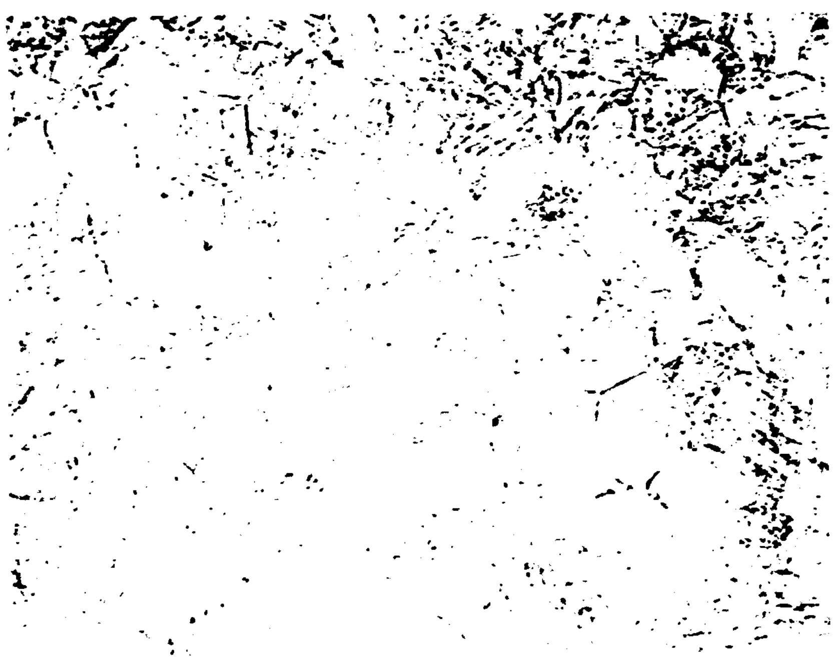


b. 5.7 x 15 cm Diameter Bar Mag. 500X

Figure 5. SEM micrographs of PH13-8Mo bar showing (a) the presence of stringers on fracture surface and (b) the brittle nature of stringers relative to adjacent ductile area.

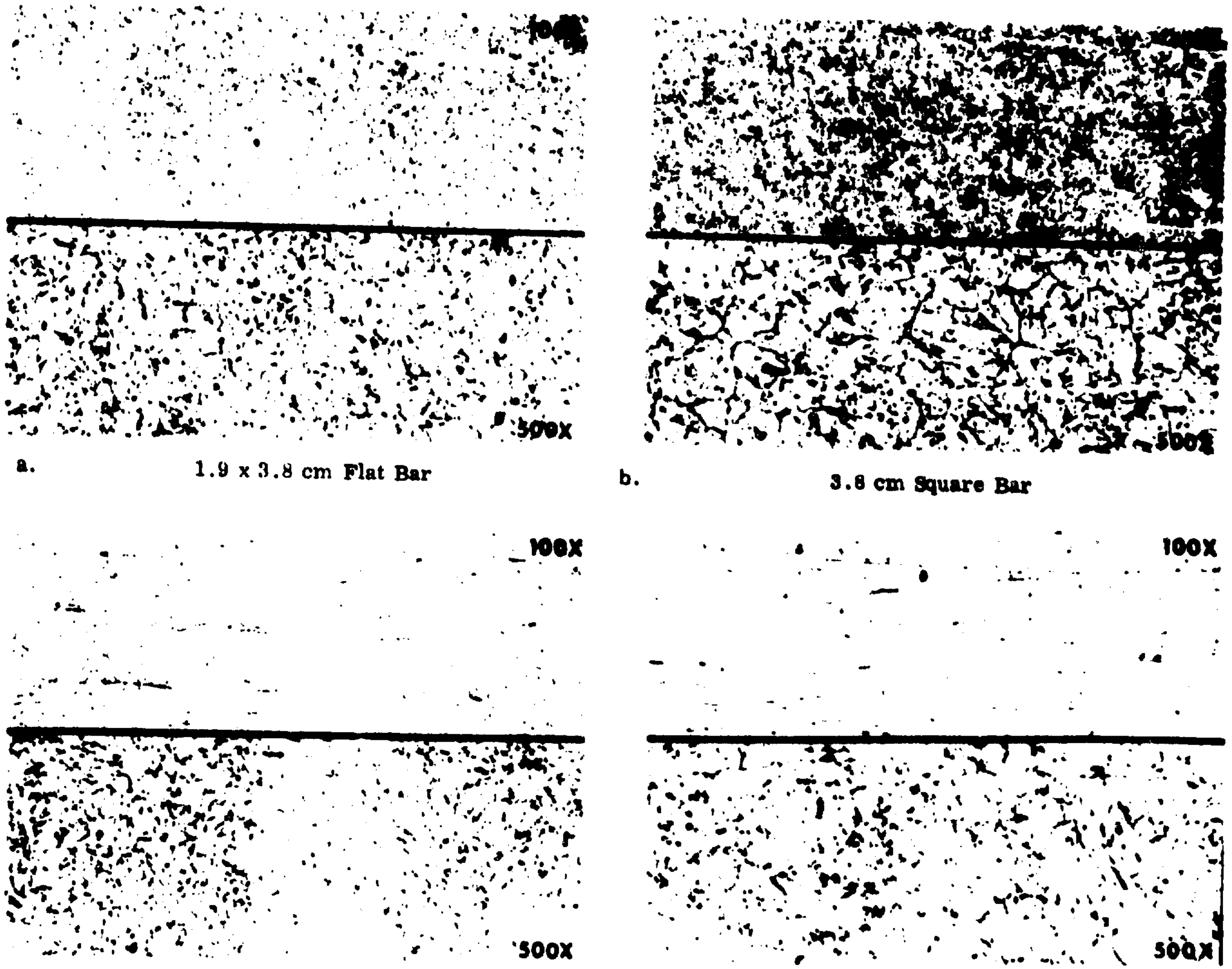


a. 7.6 x 15 cm Bar (Long.) Mag. 100X



b. 7.6 cm Diameter Bar (Trans.) Mag. 400X

Figure 6. Microstructures of 15-5PH bars showing (a) a single stringer and (b) retained austenite.



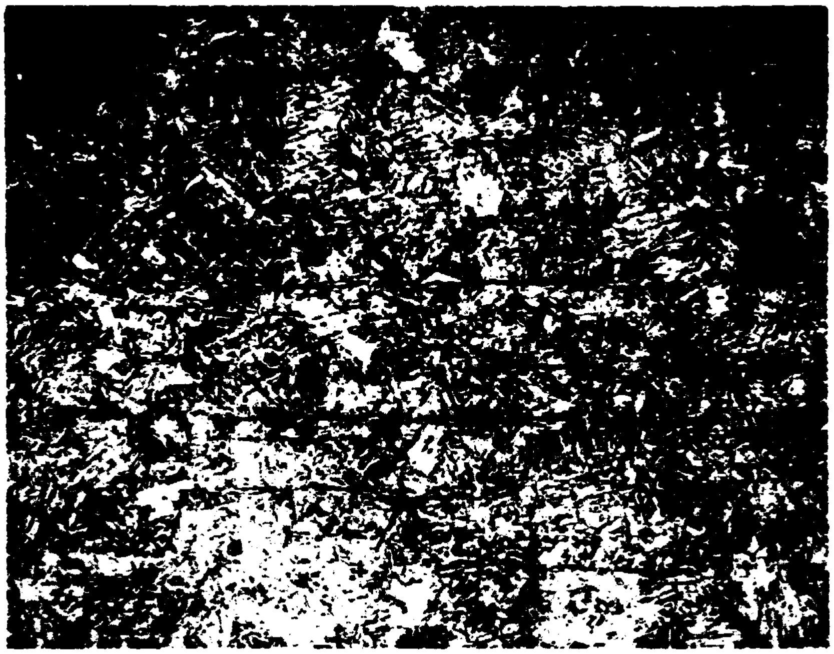
a. 1.9 x 3.8 cm Flat Bar

b. 3.8 cm Square Bar

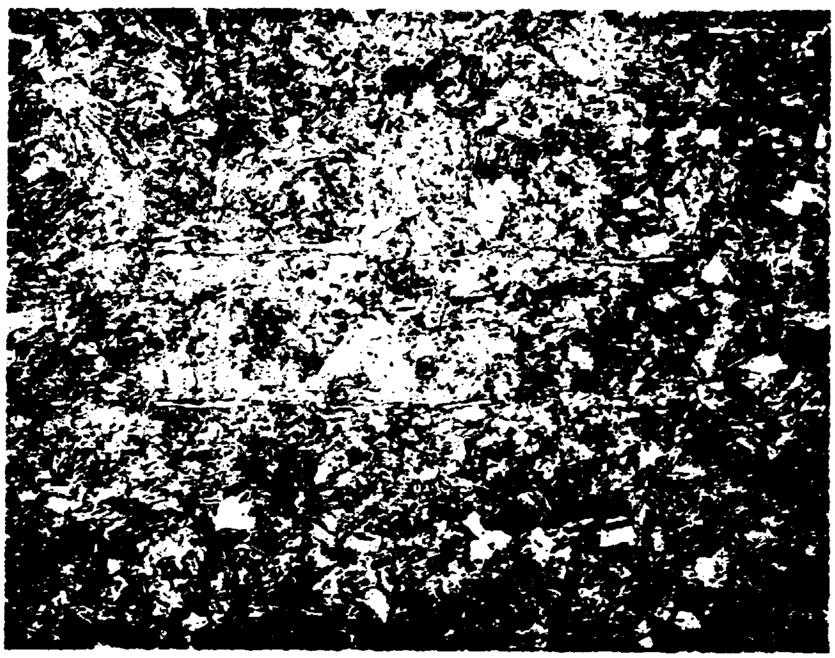
c. 3.8 cm Round Bar

d. 5.4 cm Plate

Figure 7. Photomicrographs showing the variations in microstructure among four 17-4PH heats.



a. 7.6 cm Diameter Bar Mag. 100X



b. 7.6 x 15 cm Bar Mag. 100X

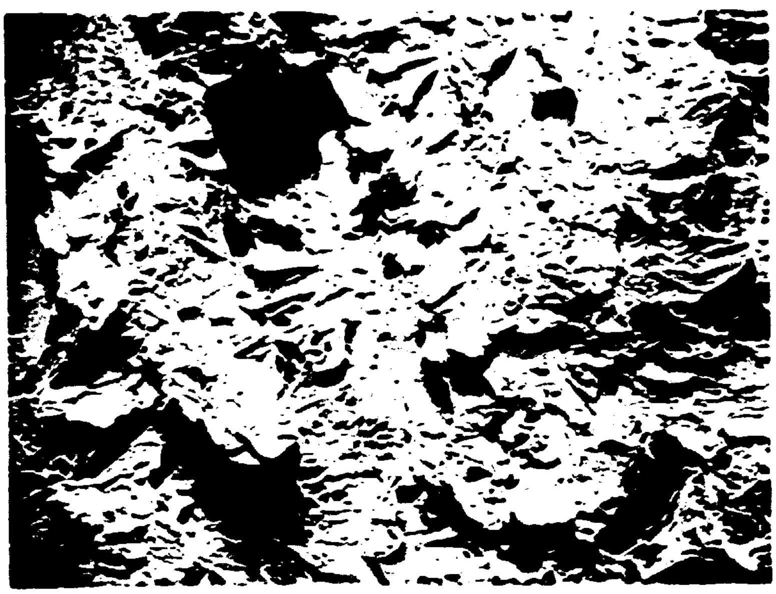
Figure 8. Photomicrographs of 17-4PH bars showing the presence of stringers.

a. 5.4 cm Thick Plate Mag. 15X

b. 5.4 cm Thick Plate Mag. 500X

Figure 9. Photomicrographs of 17-4PH plate showing (a) the presence of banding and (b) delta ferrite stringers.

a. 5.4 cm Thick Plate Mag. 20X



b. 5.4 cm Thick Plate Mag. 500X

Figure 10. SEM micrographs of 17-4PH plate showing the brittle nature of fracture surface indicative of SCC.

APPROVAL

STRESS CORROSION CRACKING EVALUATION OF MARTENSITIC PRECIPITATION HARDENING STAINLESS STEELS

By T. S. Humphries and E. E. Nelson

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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